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PROSPECTING IN NEW BRUNSWICK (SESSION I)

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Department of Natural Resources
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Hon. Gerald S. Merrithew

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PROSPECTING IN NEW BRUNSWICK
(SESSION I)

Mineral Resources Division
Department of Natural Resources
New Brunswick

This is a Federal-Provincial Development Project, funded under the Minerals and Fuels Subsidiary Agreement of the Canada-New Brunswick General Development Agreement by the Government of New Brunswick and Canada Department of Regional Economic Expansion.

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NOTES

ON

PROSPECTING IN NEW BRUNSWICK

by

W.E. Hale

University of New Brunswick

&

Department of Natural Resources

A
Program
of
six sessions

This is a Federal-Provincial Development Project, funded under the Minerals and Fuels Subsidiary Agreement of the Canada - New Brunswick General Development Agreement by the Government of New Brunswick and Canada Department of Regional Economic Expansion.

January 1981
Revised January 1982

Fredericton, N.B.

Prospecting in New Brunswick
by
W.E. Hale

Program Outline Jan. 1982

Program Outline
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PROSPECTING IN NEW BRUNSWICK

by

W.E. Hale

(Required by all participants) References

Course Text: Lang, A.H., (1970). Prospecting in Canada, 4th Ed., G.S.C. Economic Geology Report No. 7.

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NOTES

on

PROSPECTING IN NEW BRUNSWICK

by

W.E. Hale

SESSION ONE

Introduction and Minerals

January '81
revised January '82

Notes on

PROSPECTING IN NEW BRUNSWICK

W.E. Hale

SESSION ONE

Introduction and Minerals

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SLIDE SETS (JLM Visuals)

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2. Common Rock-forming Minerals (JLM #104).
3. Metallic Minerals (JLM #106).
4. Non-metallic Minerals (JLM #108).
5. Exotic Minerals (JLM #102).

FILM - Awakening Giant

Notes on
PROSPECTING IN NEW BRUNSWICK

W.E..Hale

SESSION ONE
Introduction and Minerals

1.1.0 GENERAL INTRODUCTION:

1.1.1 Program

This prospecting course consists of six sessions of at least three hours each during which you will receive information in the form of: lectures; data sheets (hand-outs); films; slides; recommended readings in various publications; supervised practice with minerals, rocks, maps; demonstrations of equipment, etc. A qualified instructor will provide material and explanations for you during these sessions.

1.1.2 Purpose

The purpose of the course is to introduce you to the practice of prospecting. To become a professional, or even a well-qualified, amateur prospector will require much more time and study than that spent here with the instructor. Obviously, the more time, study and practice you put in, the better qualified you'll become. (A course outline of main topics and a list of references are provided with the notes for this first

session. The first two references are required, the 'Additional References' are optional and some of them go well beyond the interests of the average prospector but he/she should be aware of them if he/she wishes to go deeper into some subjects only briefly covered in these notes).

(In the preparation of this short course, no prior knowledge or experience has been anticipated. Thus, for those who have studied on their own or who have already prospected, some of the course material will be familiar in which case, it may serve as a review or clarification).

1.1.3 Prospecting

a. Definition

Let's now consider 'prospecting' itself. In very simple terms, we can define 'prospecting' as, the search for and recognition of occurrences of minerals and mineral fuels that may be sufficiently large and of adequate grade to allow economic recovery of all or part of the deposit for commercial use. This description may require further explanation of some terms frequently used in connection with prospecting.

b. Search

The 'search' for deposits that have commercial possibilities takes many forms. The traditional or popular view of this activity by the prospector is that of a rugged individual, deep in the bush with his canoe or on foot and equipped with only his camping gear, compass, map, a prospector's pick and a hand lens. Travelling in areas far removed from cities and settlements and using his skills of observing

carefully and breaking off samples of rock or scooping up pans of gravel, he suddenly 'strikes it rich', where no one else has travelled or, if they have, they neglected to observe and sample the materials under their feet. This type of search depends largely on location (where deposits are exposed on the surface and few people have explored the area), careful observation (to note evidence of ore that others may have missed), knowledge of and experience with the evidence that indicates commercial deposits, and luck. Commercial deposits have been found this way, particularly in the Canadian Shield, prior to World War II. It is also reasonable to expect some additional deposits to be found this way, particularly where fresh evidence of interesting mineralization may be exposed on the surface by new road-cuts, floods, construction, excavations, forest fires, avalanches, landslides, etc. that remove soil from underlying rock.

Since World War II two major factors have dramatically changed the search for mineral deposits. The first of these has been the tremendous increase in demand for more and new minerals and mineral fuels. In addition, during the war, techniques for detecting metals beneath the water or land surface were invented or improved for military purposes, e.g., the detection of submarines and explosive mines. These detection techniques, developed and improved since the late '40's and '50's, have also changed the search for minerals and fuels, particularly in the case of those methods that can be employed in air- and space-craft which explore in hours 1,000's of times the area that a pre-1940 prospector would investigate in a life-time on the ground. Whereas some of these new techniques are complicated and

expensive relative to the individual prospector's methods, others, involving the sampling of soils, stream sediments and waters for minute traces of metals and hydrocarbons (that can be analysed at reasonable cost in government or commercial laboratories) merely represent a refinement of the traditional prospector's search techniques. Fortunately, in Canada and in some other countries, much of the more expensive and complicated search techniques have been carried out by federal and provincial government agencies that publish the results for use by any interested person or group. Thus, the modern prospector has the advantage of being able to use new methods and information in his search. (Later sessions will include some reference to published results of airborne and other types of government surveys). The widespread use of the new techniques has resulted in the discovery of many new deposits that were missed by, or hidden from, the old-time prospectors. The modern, independent prospector, therefore, cannot expect to simply 'stumble onto' a new find so easily as he might have done 50 years ago but, on the other hand, he now has for guiding his search valuable, inexpensive information that was unknown to the pre-World War II prospector.

c. Recognition

The 'recognition' of deposits that have commercial possibilities also deserves some explanation. Early prospectors searched primarily for minerals that "glitter" - native gold, native silver, 'sulphides' and gemstones, or like iron minerals, have characteristic red and yellow 'ochre'-type weathered products that are obviously and distinctly different from the

rocks or gravels in which they occur. Modern prospectors are looking for not only lower grade precious metals and sulphide mineralization but new minerals that may differ little in appearance from the rocks in which they occur. Thus, a better knowledge of mineralogy and an awareness of the commercial demand for a far greater variety of minerals is required if the present-day prospector is to recognize economically interesting occurrences that may have had no value 50 years ago. A good example of the change in demand for and recognition of minerals is that of uranium-bearing minerals such as pitchblende, uraninite and others. These now very important minerals would have been only curiosities 50 years ago and prospectors of that time would not have recognized them if they had been, as some of them were, standing on a future uranium mine.

d. Occurrence

Occurrence is a term used by geologists, prospectors and others to indicate only that a mineral or mineral fuel has been identified or recognized in the field, at a specific site or location. The term does not indicate anything concerning commercial possibilities. A gold occurrence, for example, contains gold, that is, gold is known to exist at a particular locality, but we don't know, from this term alone, whether or not the gold is mineable. 'Deposit' commonly signifies economic possibilities for an occurrence but this term too is far from exact. The prospector should also realize that external economic conditions (supply, demand, cost and price) can change an occurrence or deposit from unmineable to mineable, without any change in the amount or kind of minerals present in it.

Similarly, a new technique for mining or processing may change a deposit that has been known to exist for many years from non-commercial to commercial. Indeed some deposits in Europe, that were thought to be exhausted a hundred years ago, are now being re-evaluated because what was 'waste' then may be 'ore' today. The 'key' to clear thinking and expression in the use of these terms is 'ore'. When we add this term to 'occurrence' or 'deposit', we know we are speaking of a mineral concentration that can be commercially operated, i.e., mineral products can be obtained from the occurrence at a profit.

e. Minerals, Mineral Fuels, Other Terms

'Minerals' will be described in greater detail below but at this stage the prospector should know that certain minerals, the mineral fuels and the rocks that contain them are the targets for which the prospector and others are searching. There are approximately 2,000 minerals that can be found on the earth's surface. Of these, perhaps 100 are either abundant enough or valuable enough to warrant the prospector being able to recognize them. Minerals make up the bulk of the rock, soil, sand, gravel and clay that we find on the surface of the land and the bottom of lakes, seas and oceans. 'Mineral fuels', such as coal, oil and natural gas form in a manner similar to that in which some minerals are formed but, in addition to the mineral-making process, mineral fuels require plant or animal concentrations that are not necessary for other minerals. 'Rocks' are solid concentrations of one or more (valuable and otherwise) minerals.

In tabulations of mineral products (in the Canadian Minerals Yearbook, for example) you will note additonal terms

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In tabulations of mineral products (in the Canadian Minerals Yearbook, for example) you will note additonal terms

that are important for the prospector: 'metallic minerals', 'non metallics', 'fuels', 'structural materials', 'dimension stone', etc. These refer to specific types of minerals, and aggregations of minerals.

f. Size and Grade

"Sufficiently large and of adequate grade", refers to the conditions necessary for an occurrence to be ore i.e., mineable at a profit. The determination of size and grade commonly requires a geologist, mining engineer and metallurgist to confirm that the mineral occurrence can be profitably mined and the ore from it economically processed. However, the prospector should have some idea of tonnage and grade for commercial production of various minerals and mineral products so that he can avoid spending his time and resources on occurrences that are unlikely to 'make ore'. This requires knowledge of producing deposits. These grades, reserves and rates are published in annual reports of individual companies, in the Northern Miner, Financial Post, in government publications and in other sources available in libraries. Determining sufficient tonnage and adequate grade may require a great deal of time and expense and commonly it is done in stages, often by several companies in turn, each working for several years at a time. The determination is an economic one taking into account factors such as: markets, prices, transportation costs, processing, etc., on which the average prospector does not have the necessary up to date information. Canadian 'prospects', those occurrences that appear to have some commercial possibilities, outnumber producers by about 3,000 to 1 and proving that a prospect can become a producer may involve an

expenditure of millions or 10's of millions of dollars before a decision to produce can be reached. After that decision is reached, modern mine and milling plants cost in the order of 100's of millions of dollars. Proving 'sufficient tonnage and adequate grade', i.e. reserves, is generally the most complex, risky and expensive operation that occurs between prospect and producer. This operation is commonly known as 'evaluating' a deposit. The prospector with a realistic appreciation of the time, cost, experience and expertise involved in eliminating or reducing the uncertainties about a deposit or prospect will be in a better position to negotiate the sale or option of his/her claims. He will also realize that there is not always a clear-cut, arithmetic distinction between what is commercially workable and what is not. For example, a copper occurrence north of the Arctic Circle would require larger tonnage and/or higher grade to be profitable than a similar deposit on the Atlantic or Pacific Coasts. Similarly, a copper occurrence may not be mineable at $ .50/pound of copper on the international market but may suddenly become 'ore' with a copper price of $1.00/pound.

g. Economic Recovery

'Economic recovery', means obviously that the total of the expenditures involved in mining, processing, transporting, taxation, marketing, etc., must be less than the net amount to be received from the sale of the mineral product. There are many uncertainties connected with verifying that recovery of the products from a deposit will, in fact, be economic. Competitive discoveries elsewhere, labour-management conflicts, dollar-value changes, trade restrictions, technological substitutes, etc., all

influence 'economic recovery' of metals, minerals and mineral fuels. Analysis of all these and related influences is beyond the scope of this course. Even economic decisions made by teams of senior, experienced scientists, engineers and business executives of companies, banks, and governments can be wrong when new factors or changes in old factors occur unexpectedly. The example of this kind that will be used for many years to come is that of the changes in energy (generally required in large amounts for the processing of most mineral products) costs that took place unexpectedly in 1973. This change in a single, external factor resulted in some deposits that were thought to be 'economic' becoming non-economic or unrecoverable whereas many deposits or mineral fuels such as coal, that were previously considered uneconomic, suddenly became highly profitable.

Those unfamiliar with minerals and mineral deposits often believe that a deposit is all recoverable and commercially useable, and therefore saleable. This is seldom the case. If we planned to produce crushed and ground limestone, for example, we could probably mine (quarry) from extensive occurrences of this rock exposed at the surface, in areas such as those in and around Saint John, N.B. In this case, there would be little 'waste'. However, even in this relatively simple type of mineral recovery, we would find certain differences in the rock (hardness for grinding, impurities, etc.) that might make it worth our time and effort to selectively mine certain parts of the rock mass rather than the whole. Thus, we would prefer to recover only 'part' of the deposit. A more complex and costly problem arises in connection with most metallic mineral deposits. For example,

when we speak of the lead-zinc deposits of Bathurst-Newcastle, N.B., we ignore the sulphur, silica, iron, and many other elements with which the lead and zinc are combined and from some of which they must be separated in order to yield saleable products. 'Waste' minerals go into 'tailings' in the processing of the ores to obtain the valuable elements. These 'waste' minerals have had to be mined and processed in order to separate them from the more valuable lead and zinc minerals. This mining and processing of what becomes waste material in a deposit is costly, even though it yields no return. Much research is being applied to the utilization of what is now waste and success in this field has been achieved with the Bathurst ores. In any case, prospectors and others associated with the mineral industry will be familiar with the fact that 'economic recovery' of all the contents of an ore deposit is very rare. Much more common is the case in which only a relatively small 'part' (by weight or volume) of a deposit is actually recovered for commercial use.

h. Commercial Use

'Commercial use', means that the products obtained from a mine or other system for recovery must be useable to the financial advantage of somebody: a company, a government, another individual, somewhere: locally, nationally, internationally, at some time: present or future. In other words, there has to be a reason: profit, yield, return or some similar justification for investing the money necessary to open and operate a deposit, rather than leave the deposit as is for now and invest the money elsewhere. Some governments and individuals don't like the ideas of profit, return on investment, financial gain, etc., but nobody

is going to open and operate a deposit for long unless there is a) a need (market) for the product(s) and b) a commercial advantage in making the effort to 'win' these products. The profit or other form of commercial advantage may be received by individuals, companies, government or the 'people' but someone or group has to commercially succeed in the recovery of a deposit, otherwise the $100,000,000 or so required to open a deposit would be better invested in bonds or similar security, at a 'safe rate', and 'returns' from these investments applied to economic and social progress.

1.2.0 MINERALS AND MINERAL FUELS

1.2.1 Approach

In the search for mineral and mineral fuel occurrences, the prospector uses various items of equipment: compass, maps, vehicle, etc., to travel over and investigate ground. To do more than just cover ground in the expectation that an obvious orebody will 'present itself' to him, he also needs some basic, practical knowledge of: a) ore minerals, b) common rocks, minerals, soils, water, etc., and c) land forms and their relation to underlying rock formations. He also needs to know where and from whom he can obtain information he himself does not have.

Most of the knowledge required by the prospector comes from the broad fields of geology and economics. Geology, the science of the earth as a whole, in time and space, is so broad in its scope that geologists themselves specialize in one or several related sub-fields of the many that make up this science: geophysics, geochemistry, geomorphology, mineralogy, petrology,

palaeontology, structural geology, economic geology, etc., etc. Similarly with economics, which includes all knowledge relating to money and its role in human affairs, the subject involves much more than the prospector requires.

1.2.2 Geology

From geology the prospector should learn some: mineralogy (the foundation of physical geology and the basis of prospecting since all economic deposits consist of minerals or mineral fuels in some form), petrology (the study of rocks which are composed of minerals in various combinations and in which all economic deposits occur), structural geology (dealing with the shape and spatial arrangement of bodies of rock, ores, etc. and the causes for their dislocation from their original positions), stratigraphy and sedimentation (the study of layered rocks and gravels, sands, clays, etc.), economic and mining geology (involving ore deposits and the methods and costs of getting the ore out of the ground). The prospector will also benefit greatly from an understanding of geomorphology (the study of present-day land forms from which at least some of the geological history of an area can be interpreted. Geomorphology may also provide 'clues' as to what occurs in the rocks beneath the surface. In Canada, where glaciers have been active, a knowledge of Pleistocene Geology is essential in prospecting. Two younger branches of geological science have contributed dramatically to the discovery of ore bodies and deposits of mineral fuels. Exploration geochemistry (the study of the distribution of ore elements in earth materials) assists the prospector in

understanding the behaviour of these elements, particularly when they are subjected to deep weathering and erosion and thus become redistributed in minute (trace) amounts in soils, surface waters, etc. Geophysics involves the study of the nature of and changes in physical properties of earth materials including those that are related to ore bodies and deposits of mineral fuels. 'Buried' orebodies have been identified from the air and ground surface using geophysical instruments such as the magnetometer.

Whereas the individual branches of geology require many years of study for their full understanding, the prospector needs only to understand the principles and some of the applied or practical techniques used in ore search. (In addition to the two required references for this course, the scope of geology and the concerns of some of its branches are indicated in Additional References 2, 6, 9, 10. For an explanation of most geological terms a handy guide for the beginner is Additional Reference 1).

1.2.3 Economics

From economics, the prospector needs primarily the knowledge relating to economic evaluation of mineral deposits, i.e. what is ore at a specific time, in a particular place. A broader knowledge of economic studies: international finance, trade barriers, taxation, government fiscal policy, etc., is not essential for the prospector. Economic evaluation as it applies to mineral deposits and mines is dealt with in Additional References 3, 7, 8 and 9).

1.2.4 Mineralogy

a. General Information

(Your first practical exercise in this prospector's program is intended to provide some contact with minerals. You should refer particularly to the appropriate sections of your texts and lab manuals. These will be identified by the Instructor who will also indicate the appropriate use of other reference material. The following notes may also prove helpful).

Mineralogy, that branch of the geological sciences that incorporates our knowledge of minerals, is considered to be the source or foundation of physical geology. The 'science' of mineralogy developed in the 1400's when the 'Father of Mineralogy', Agricola, began for the first time, a systematic, factual study of the physical properties of minerals as a basis for understanding them. (Agricola, a physician, studied minerals and mineral deposits in what is now Germany and produced several texts in Latin with many interesting illustration of prospecting, mining, and processing of that time. A former President of the U.S.A., Herbert Hoover, a mining engineer by profession, and his wife, a scholar of Latin and Greek, translated one of these early texts of Agricola and had reproduced the original illustrations so that we have today a record of those early times in "De Re Metallica", available in many libraries. The reader of this modern book may be surprised to find early techniques illustrated that are still in use today, particularly for placer deposits in gravels and sands).

Prior to Agricola and his systematic study of minerals, and even after it in some quarters, minerals were commonly

studied and classified according to their mystical powers as charms against: ill health, wounds, death, bad luck, etc. They were also studied for their medicinal powers but in a 'witch doctor' style rather than as is done in modern medicine. An excellent and interesting account of early ideas concerning minerals and these supposed powers can be found in, "Birth and Development of the Geological Sciences", by F.D. Adams, Dover Publications, 1940. (It may be of interest to know that the late Dr. F.D. Adams was a Canadian and professor of geology at McGill University for many years).

b. Definition

There are many definitions of minerals that involve an understanding of chemistry, physics and biology, beyond the scope of this course. For your purposes, the following information about minerals is important.

Minerals are natural materials. This means that minerals, in the strict sense of the term, are those materials produced by natural processes from lava, for example, or from seawater but not from processes controlled by man. Steel, although produced from iron ore minerals such as hematite, is not a mineral even though it has characteristics that are the same as, or similar to, some minerals. Man has, for reasons of cost, also made materials such as diamond but, strictly speaking, these man-made, artificial or synthetic materials are not truly minerals. In any case, in prospecting we are generally searching for materials that nature, other than man, has produced and concentrated for us. As with most definitions, there are exceptions and if we were to examine an old mine, or the tailings from it, we would be

dealing with minerals that man had at least redistributed.

Minerals are inorganic materials. By 'inorganic' we mean non-life, i.e., minerals differ from many natural materials such as plants and animals in that minerals do not reproduce themselves nor are they ordinarily produced by living organisms. (Some early investigators of minerals argued that since God gave the power to reproduction to the animal and vegetable kingdoms, he surely would not deny the mineral kingdom the joys of reproduction). Repeated experiments indicate that minerals are 'dead' or inorganic in this sense. Here also there are exceptions and some minerals form more easily where biological (organic) processes are in operation. Some organisms, including man, require minerals for their structures (bones, shells) and when they die, these skeletons and shells become much the same as mineral deposits. However, these exceptions are minor in terms of the majority of minerals that do form and are forming without any evidence of organic 'influences'.

Minerals are chemical elements or compounds. From the prospector's viewpoint, it is not necessary to know about all the particles and energies that combine in atoms and molecules to form matter in general and minerals in particular. The prospector must be able to identify earth materials that can be seen with the naked eye or the hand lens. These are the stable (in terms of human time) products of a variety of sometimes complex chemical processes. These processes may take place at very high temperatures (1000°C), for example, in the lavas poured out from active volcanoes. Minerals may also form from low-temperature processes such as the precipitation of salts from

sea-water to produce halite (rock or table salt) and sylvite (potash) and other minerals. Processes in which pressure is an important influence on the formation of minerals begin when surface minerals are forced down, through buckling of the crust, into deeper, hot, high-pressure zones beneath the earth's surface.

Some minerals such as those known as the 'clay minerals' serve as dependable clues of the surface process by which they formed, others, such as quartz, form under many different conditions of temperature and pressure and their presence is not necessarily a clue to understanding the process that formed them.

The earth's crust (the relatively thin outer shell of the planet) is composed of predominantly igneous (previously molten) rocks that locally 'pop' through the surface, as for example near Pokiok on the Trans Canada Highway (TCH) and also near Eagle Mountain (near Welsford) on the Highway between Fredericton and Saint John. (Other extensive exposures of these igneous rocks occur near St. George along the St. John-St. Stephen Highway). The average of hundreds of analyses of igneous rocks, that make up the bulk of the crust, is tabulated in Appendix III, p. 276 of your texts (Lang, 1970). A quick survey of this table will suffice to show that <u>oxygen</u> and <u>silicon</u> are by far the most abundant elements (smallest components of matter as we generally know it) in these rocks and hence in the crust. It is not surprising, therefore, to learn that the most abundant minerals, '<u>silicates</u>', are those that are chemical combinations or compounds of these two elements -- oxygen and silicon. These two

most abundant elements, oxygen and silicon, are attracted to one another like the oppositely-charged poles of a magnet. Oxygen also combines with other abundant elements such as iron, aluminium, etc. Oxygen combines with these and other elements in different configurations depending on it's local abundance at a particular time when minerals are forming under varying conditions. This results in many different minerals having oxygen and silicon plus other elements. In a similar manner, sulphur combines with elements such as lead, copper, iron, etc. to form the sulphides: galena (PbS), chalcopyrite ($CuFeS_2$), pyrite (FeS_2) and so on.

The natural processes by which minerals form are commonly imperfect and it is a rare instance when impurities in the form of minute amounts or traces of 'foreign' elements are not present in a mineral compound. Thus, the chemical composition of minerals is often reported as ranges, limits or end-members between which composition may vary. For example, the most common mineral known, feldspar, always consists of oxygen, silicon and aluminum but it also has potassium in orthoclase, sodium in albite, and calcium in anorthite. Orthoclase ($KAl_2Si_3O_8$) generally contains some sodium. Albite ($NaAl_2Si_3O_8$) and anorthite ($CaAl_2Si_2O_8$) form a series, known as 'the plagioclase series', in which the sodium (Na) and calcium (Ca) can be present in varying proportions.

Minerals thus have less exactly defineable chemical compositions compared to 100% pure, man-made chemicals. On the other hand, the departures from 100% purity in minerals is strictly controlled by the geometric arrangement of the most

abundant elements which form networks that serve as 'seives' or 'filters' into which only a certain number of other elements of an acceptable size and energy can enter.

Dependable determination of the chemical composition of minerals became possible with advances in analytical chemistry 100 or so years ago. These led to a classification of minerals known as, "Dana's System of Mineralogy" from which much was learned of the origin and occurrence of minerals.

Minerals may exhibit regular, smooth, planar surfaces. Well before modern chemistry permitted accurate determination of mineral compositions, early scientists observed that some minerals, such as pyrite, calcite, feldspar and others, were often found to occur with characteristic crystal boundaries. By 'characteristic' in this sense we mean that regardless of size, the smooth surfaces of a particular mineral were always found to be arranged in the same or similar geometric pattern. Expressed another way, the angles between corresponding faces on crystals of the same substance were the same, regardless of the size of those crystals. (Your instructor will demonstrate with your mineral sets and illustrate this for you).

The discovery of regularity in the arrangement of crystal faces was the basis of a systematic study, crystallography, of mineral crystals and their classification into groups having the same geometric characteristics. This classification also contributed to the recognition and understanding of minerals. It was and is still used as a means of identifying those minerals that commonly have prominent (to the naked eye or hand lens) crystal surfaces.

A limitation in the use of crystallography for the identification of minerals results from the fact that a particular mineral (quartz for example) may have easily observable crystal surfaces in one occurrence (the instructor will show you a sample of rock crystal) whereas the same mineral (chemically SiO_2) in a different occurrence may not have any visible crystal faces (Chert or other examples of quartz will serve to illustrate this). This difference in the quality or size of crystal surfaces is due to the differences (of time, availability of the elements, heat, pressure, etc.) in conditions during the growth of the mineral. Under certain conditions, a mineral compound will grow into a large crystal until all the elements it needs are used up or the conditions change: under other conditions, 1,000's of tiny, individual crystals (too small to be seen with the naked eye) will be formed and thus use up all the available elements required for that same mineral compound.

As information on the crystal forms of minerals was expanded by observations and comparisons from many parts of the world, but particularly in Germany, a very important conclusion was reached. It was suspected by early scientists in this field that minerals must consist of extremely small units, like bricks in a house, and that these 'bricks' are characteristic, i.e. have specific geometric properties for each mineral compound, regardless of the size of the final form or 'house' in which they are found. This deduction about the interior of mineral crystals which was later supported by the growing knowledge about the chemical composition of minerals, had to wait for almost 200

years for its confirmation.

Minerals have a specific arrangement of matter (unit cell) which is unique for all occurrences of that mineral. Bear in mind that the study of minerals up until the 1920's was carried out from two main approaches. On the one hand, crystallographers compiled more and more information that confirmed the regularity of external crystal surfaces and, at the same time, chemists were providing more and better data on the composition of these substances. It should be appreciated, however, that the crystallographer dealt with the minerals he studied in their solid, undivided or intact form. The mineral chemist, on the other hand, had to destroy or decompose the mineral into its constituent components before he could identify them. What was lacking was a method whereby mineralogists could 'see', at great magnifications, not only what elements (atoms) were present in a mineral and their relative amounts, but also where each element was located in the 'bricks' that made up the mineral 'structures'.

X-rays provided the means of getting 'inside' mineral crystals without destroying them. A father and son team at Cambridge University, England, published in 1924 the first 'pictures, from inside mineral crystals and these, with others later, confirmed the suspicion of earlier mineralogists that crystal planes, like the sides of a house, were merely extensions of planes in smaller units (bricks) or unit cells. When the crystal form, chemical composition and x-ray data on minerals were combined, they allowed for a dependable classification of all minerals known and a fool-proof means of identifying them.

The prospector can have an identification made by x-ray techniques in a lab. to which a specimen is sent but he must await the result and pay the expense so it is wasteful to have this done for common minerals that he should be able to identify by the simpler means described and practised in this course.

c. Rock-Forming Minerals

Rocks are collections or accumulations of one or more minerals. These rocks form as a result of the various natural, geological processes that are continually operating on and in the earth. Any of the 2,000 or so minerals known can contribute to the bulk of a rock. There are, however, some minerals that, because of their abundance (based in turn on the abundance in the crust of certain elements such as oxygen and silicon), make up most of the earth's crust. Silicates (those minerals containing oxygen and silicon in varying combinations with additional elements such as iron, magnesium, etc., added to these combinations) are by far the most abundant (chemical category) of minerals and they naturally, therefore, make up most rocks (99%). Variations in the manner of combination of the oxygen and silicon and the additional elements with which these combinations unite allow for many subdivisions of silicates. However, arranging these abundant minerals into groups and series that take into account ranges of composition possible for essentially the same atomic structure, allows us to identify only a few that comprise this 99% of the earth's crust: the feldspars, quartz, micas, amphiboles, pyroxenes and olivine, in roughly that order of abundance.

In addition to the silicate minerals, a few others contribute to the bulk of rocks, either as minor constituents, among the silicates, or locally as the major rock-forming minerals. These include: the carbonates (example, calcite, $CaCO_3$), oxides (example, hematite, Fe_2O_3), sulphates (example, gypsum, $CaSO_4.H_2O$), and sulphides (example' pyrite, FeS_2).

Ore minerals, much less abundant generally in the crust than rock-forming minerals, are never-the-less associated with certain rock types. Although this relationship between ores and specific rocks is not perfectly controlled in nature (For example, gold can occur in ore grade in some igneous rocks containing only certain silicate minerals; it can also occur in veins within carbonates and also in sedimentary rocks of widely varying mineral composition.), the prospector enjoys an advantage in his work if he can identify major rock types, chiefly on the basis of the predominant minerals they contain. This obviously requires a progressive familiarity with the rock-forming minerals. A set of these minerals is provided for practise (and is illustrated in Slide Set JLM104).

d. Ore-Forming Minerals

An ore is a mineral or combination of minerals from which one or more products can be extracted at a given time, in a given place, at a profit. More information on ores and their occurrence will be presented in later sessions of this program. In this session we are considering ore minerals as such and not as ores. This is an important distinction. Ore minerals (for example, chalcopyrite, $CuFeS_2$) may occur in a rock as a minor (in

volume) constituent, in quantities and distribution such that it cannot be extracted economically. Thus, it and the rock which contains it cannot be considered ore. Hematite (Fe_2O_3) is another example since it may occur as a cement holding other mineral grains together in a common sedimentary rock, such as sandstone, and, in such cases, there may be no available method of extracting it profitably. On the other hand, hematite, under certain natural conditions, may form to the exclusion of almost all other minerals and thus be concentrated in a relatively pure state from which it can be economically mined as an iron ore.

To be able to distinguish between types of occurrence described above and to be able to recognize ore minerals in small quantities that may be clues to larger concentrations, the prospector must acquire proficiency in the recognition of these minerals. (Examples are provided in the mineral sets and are also illustrated in Slide Set JLM106).

Ore minerals are of two main types: metallic and non-metallic. The metallic ore minerals are generally fairly easy to recognize. Their metallic lustre (Data Sheet 1) is suggestive of metals, as the term indicates, and they therefore appear distinctively in a rock composed predominantly of the more abundant, non-metallic and hence less distinctive, rock-forming minerals. (The instructor will demonstrate and illustrate this difference better than words can describe).

A more difficult problem of identification arises with the non-metallic ore minerals. Like the metallic ore minerals, these non-metallic types depend on their abundance and distribution in a rock for their economic possibilities. The difference lies in

the fact that non-metallic minerals are commonly not distinctive relative to the non-economic, rock-forming minerals in which they may occur or with which they may be associated. Furthermore, their economics may be much 'tighter', in the sense that their unit value ($ per lb, per ton) is usually much lower than for the metallic ore minerals, such as gold, silver or even lead and zinc minerals. For example, calcite ($CaCO_3$) is a widespread and, in some cases, rock-forming mineral. (Fortunately, it can be easily recognized with the use of cold, dilute HCl with which it fizzes or effervesces). Distributed uniformly through a rock consisting primarily of non-economic rock-forming minerals, calcite has no economic value. However, under some strict conditions, calcite may form as the only mineral stable under those conditions and it may form with a very high degree of purity. In deposits of the latter type, the calcite (limestone is the rock composed of predominantly calcite) may have economic significance and thus become an ore.

Many other non-metallic ore minerals, however, do not respond to a simple diagnostic test, and they resemble non-economic, rock-forming minerals so closely that their identification is often missed or delayed. Prospectors would do well, therefore, to study these minerals carefully and be aware that good opportunities are often overlooked through the inability to recognize or identify these increasingly important ore minerals that do not 'glitter'.

e. Mineral Fuels,

Mineral fuels (oil, coal, natural gas) as noted above, are not strictly minerals and their recognition or detection involves techniques somewhat different (except for the relatively straight-forward recognition of coal) from those used for true minerals. They will be discussed briefly again in Session Two, Rocks.

f. Structural Materials

Structural materials are those used primarily and generally locally in the construction industry. They too will be commented upon briefly in later sessions of this program. Suffice it to say here that their value is impressive, as is evident from the Canadian Minerals Yearbook and the Annual Reports of the corresponding provincial departments, but their evaluation involves specialized techniques in which mineralogical identification is a comparatively minor consideration.

g. Techniques

Only the most elementary techniques, those that determine the physical properties of minerals, are dealt with in this program. The prospector should be aware of the fact that more sophisticated techniques involving chemical analysis, x-ray methods, and other now largely instrumental techniques are available for the solution of mineralogical problems. These techniques, as noted, require time and money and should be used where the extra effort is justified -- usually after prospecting has reached the stage wherein valuable minerals have been identified and quantitative, repeated results are required for lconomic evaluation. The prospector should also appreciate that

the initial 'screening' of ground or the identification and selection of a prospect still require simple field recognition of minerals as introduced in this program. Even knowing what materials should be subjected to the more sophisticated and expensive techniques generally requires a previous knowledge obtained by the simple techniques to be studied here.

1.2.5 Occurrence of Minerals

Minerals occur, associated with one another, or, in some cases, as the single constituent of various rocks. These rocks are the products of three general processes: igneous, sedimentary and metamorphic. Igneous (subsurface) processes are those in which molten or fluid, chemically complex matter solidifies (crystallizes) with falling temperatures at or beneath the earth's surface. Sedimentary (surface) processes entail the weathering of pre-existing rocks to form new or modified materials more stable under the relatively limited range of conditions, such as temperature and pressure, that we are familiar with on the surface of the earth. Metamorphic (subsurface) processes occur when rocks are subjected to significantly changed conditions, most importantly rising temperature and pressure, compared to those under which the rocks originally formed. Each of these three processes is complex and includes a range of conditions in which minerals and hence rocks can form.

All minerals form in one or more of these general processes. Minerals, in their combinations and associations, are the means from which an interpretation of the origin of rocks can

be made. Ores generally result from special conditions within these processes. The processes and the special conditions will be considered in later sessions.

DATA SHEET 1

University of New Brunswick
Fredericton

PHYSICAL PROPERTIES OF MINERALS

Definition

A mineral is a naturally occurring chemical element or compound formed as a result of inorganic processes. The chemical composition and physical properties of minerals are either fixed or vary within a definite range.

Thousands of minerals are found as component-parts of the earth's crust but only about 50 are common. These can generally be recognized by a few simple tests outlined as follows:

Hardness

The resistance that a smooth surface of a mineral offers to scratching is its hardness. Like the other physical properties of minerals, hardness is dependent on the crystal structure. The stronger the binding forces between the atoms, the harder the mineral. The degree of hardness is determined by noting the comparative ease or difficulty with which one mineral is scratched by another, or by a file or knife.

Hardness was given qualitative precision by the Austrian mineralogist, Mohs, who in 1822 proposed the following scale of relative hardness:

1. Talc
2. Gypsum
3. Calcite
4. Fluorite
5. Apatite
6. Orthoclase
7. Quartz
8. Topaz
9. Corundum
10. Diamond

Each of these minerals will scratch those minerals lower in scale and will not scratch those minerals higher in the scale.

Mohs' scale is qualitative but it is well suited for comparing relative hardness in minerals. Its use requires the simplest of equipment. With a bit of experience it will be found that the finger nail (H=2½) and a pocket knife (H=5½) will suffice as adequate tools. Other tools that can be utilized for determining hardness are: copper coin (H=3), carpenter's nail (H=4½), and a steel file (H=6½).

Minerals of hardness 1 have a greasy feel; those of hardness 2 can be scratched with the finger nail; 3 can be cut by a knife; 4 are scratched rather easily; 5 are scratched with some difficulty; those of hardness 6 and over are not scratched by a knife, and will scratch glass.

Colour

The causes of colour in minerals are varied and complex. Sometimes it is directly related to the chemical composition. Frequently it is unrelated to composition and depends on crystal structure and bond type, as in the contrast between the polymorphs of carbon-diamond and graphite. Sometimes it is due to impurities as in the coloured varieties of agate.

Some minerals have a characteristic colour that is constant from one mineral specimen to another. In such a case, this property is very important and aids in recognizing the mineral.

In other cases a mineral may occur in a variety of colours and other physical properties must be recognized before the specimen can be accurately named.

Streak

The colour of the fine powder of a mineral is known as its streak. The streak is commonly used in the identification of minerals, for, although the colour of a mineral may vary between wide limits, the streak is usually constant.

This property can be determined by rubbing the mineral on a piece of unglazed porcelain, known as a streak plate or it can be obtained by scratching a specimen with a knife. The streak plate has a hardness of about 7, hence it cannot be used with minerals of a greater hardness.

In general, most transparent and translucent minerals have a white streak; dark coloured minerals with a non-metallic lustre have a streak usually lighter than the colour; minerals with a metallic lustre have a streak often darker than the colour.

Some characteristic streaks are:

Hematite	- Indian red
Galena	- greyish black
Pyrite	- greenish black
Sphalerite	- yellow-brown
Calcite	- white

Lustre

Lustre is an optical property closely related to reflection and refraction of light. Two main classes of lustre are recognized, the metallic and nonmetallic. A sharp division cannot be made between these two classes, and minerals with a lustre intermediate between them are sometimes said to be submetallic.

The impression of lustre is produced by the light reflected from the surface of a mineral. The intensity of the lustre depends chiefly on the quantity of reflected light. The

greater the index of refraction, the greater the lustre of the mineral. It is largely independent of the colour of the mineral.

A mineral having the brilliant appearance of a metal has a metallic lustre. Most minerals with such a lustre are opaque to light and as a result, give a black or very dark streak.

All minerals without a metallic lustre have a non-metallic lustre. They are generally light in colour and will transmit light through thin edges. The streak of a non-metallic mineral is either colourless or very light in colour. The following terms are used to describe further the appearance of non-metallic minerals.

Vitreous.	Having the lustre of glass
Resinous.	Having the appearance of resin
Pearly.	Having the iridescent appearance of a pearl. This is usually observed on surfaces that are parallel to cleavage planes.
Greasy.	Looking as if covered with a thin layer of oil.
Silky.	Like silk. It is the result of a fine fibrous parallel aggregate.
Earthy.	Like earth — very dull.
Adamantine.	Having a hard, brilliant lustre like that of a diamond. It is due to the mineral's high index of refraction.

Different forms of the same mineral may show different lustre; for example, hematite may be metallic, submetallic or earthy.

Cleavage

If a mineral, when the proper force is applied, breaks so that it yields definite plane surfaces, it is said to possess a cleavage.

Cleavage is dependent on the crystal structure and takes place only parallel to atomic planes. This weakness may be due to a weaker type of bond, to a greater lattice spacing in the crystal at right angles to the cleavage, or frequently to a combination of the two.

Because cleavage is the breaking of a crystal between atomic planes, it is a directional property, and any parallel plane through the crystal is a potential cleavage plane. It is always parallel to crystal faces or possible crystal faces, since both faces and cleavage reflect the same crystal structure.

Cleavage is described according to the number of the directions of the cleavage faces, and their angular attitude to each other. Some common types are:

Basal	1 direction - 2 faces
Prismatic	2 directions - 4 faces

Cubic	3 directions at right angles - 6 faces
Rhombohedral	3 directions, no two at right angles - 6 faces
Octahedral	4 direction - 8 faces

Cleavage is also described with respect to the ease with which it is obtained: perfect - good or distinct - poor.

Fracture

The fracture of a mineral is the way in which it breaks when it does not yield along cleavage or parting surfaces. The following terms are commonly used to designate different kinds of fracture.

Conchoidal - When the fracture has smooth, curved surfaces like the interior surface of a shell. This is most commonly noted in such substances as glass and quartz. Mineraloids such as chert, and flint have well developed conchoidal fractures.

Fibrous or Splintery - When the mineral breaks showing splinters or fibres.

Hackly - When the mineral breaks with a jagged, irregular surface with sharp edges.

Uneven or Irregular - When the mineral breaks into rough and irregular surfaces.

Specific Gravity

The specific gravity (G) or relative density of a mineral is a number that expresses the ratio between its weight and the weight of an equal volume of water at 4°C. If a mineral has a G of 3, it means that a given specimen of that mineral weighs three times as much as the same volume of water.

The specific gravity of a mineral of fixed composition is frequently an important aid in its identification.

The specific gravity of a crystalline substance is dependent on two factors: the kind of atoms of which it is composed, and the manner in which the atoms are packed together.

Many students when handling minerals can acquire a sense of relative weight. For example, gypsum, with a G of 2.32, appears light, whereas barite, with a G of 4.5, seems heavy for a nonmetallic mineral. This means that one has developed an idea of an average specific gravity or a feeling of what a nonmetallic mineral of a given size should weigh. The average specific gravity for nonmetallic minerals is approximately 2.65 - 2.75, and for metallic minerals it is about 5.

A convenient tabulation follows:

	Light	Average	Heavy
Nonmetallic	Up to 2.5 (Gypsum)	2.6 - 3.0 (quartz, feldspar)	3.3 and over (corundum)
Metallic	Light Up to 4 (sphalerite)	Average 5 - 6 (pyrite)	Heavy 7 and over (galena)

Tenacity

The resistance that a mineral offers to breaking, crushing, binding, or tearing — in short, its cohesiveness — is known as tenacity. The following terms can be used to describe various kinds of tenacity in minerals.

Brittle - a mineral that breaks or powders easily, e.g. calcite

Malleable - a mineral that can be hammered out into thin sheets, e.g. gold

Sectile - a mineral that can be cut by a knife, e.g. talc

Ductile - a mineral that can be drawn into wire, e.g. native copper

Flexible - a mineral that bonds but does not resume its original shape when the pressure is released, e.g. chlorite

Elastic - a mineral that after being bent, will resume its original position upon the release of the pressure, e.g. mica.

Miscellaneous Properties

Taste - halite
Odour - kaolinite
Feel - talc and graphite
Double refraction - calcite
Reaction with HCl - calcite
Magnetic - pyrrhotite and magnetite

DATE SHEET 2

MINERAL LIST

Prospectors should know the diagnostic properties[1] and the composition[2] of the minerals listed below.

The Silicates (99% of the earth's Crust)	The Silicates (less abundant)
- quartz	- epidote
- feldspar (orthoclase & plagioclase)	- kaolinite
- mica (muscovite & biotite)	- talc
- pyroxene	- topaz
- amphibole	- garnet
- olivine	- chlorite
	- serpentine

Sulphides	Oxides	Sulphates
- galena	- hematite	- gypsum
- sphalerite	- limonite	- anhydrite
- stibnite	- magnetite	- barite
- pyrite	- corundum	
- chalcopyrite	- "Bauxite" (a rock, formerly thought to be a mineral)	
- pyrrhotite		

Carbonates	Native Elements	Other
- malachite	- copper	- fluorite
- azurite	- graphite	- halite
- siderite		- apatite
- calcite (chalk)		
- dolomite		

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1. Every mineral specimen has characteristic physical properties, some of these are diagnostic and can be used to distinguish the mineral from other minerals which are similar. e.g. striations on cleavage surfaces distinguish plagioclase from orthoclase.

2. The composition of the simple minerals e.g. carbonates and sulphides should be remembered by formula. The composition of the more complicated silicates should be remembered in a more general way; e.g. serpentine -- a hydrous magnesium silicate.